



The impact of updated Cr and Fe cross sections for fusion applications

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With collaborations from IAEA-FENDL and INDEN Project:
A. Trkov, R. Capote

*U.S. National Nuclear Data Week/CSEWG Meeting
Online*

November 30-December 4, 2020



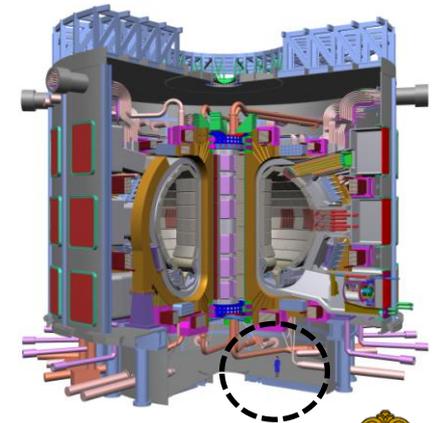
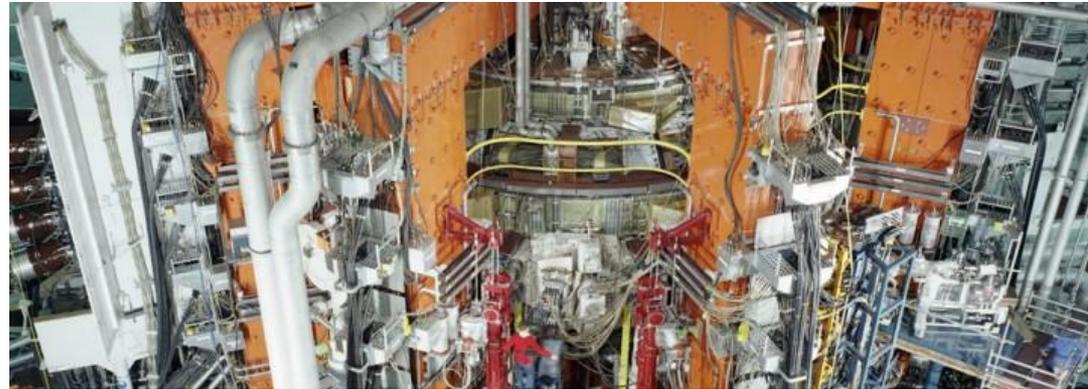
Outline



- 1) Introduction
- 2) Nuclear data libraries examined
- 3) Benchmark/Systems Analyzed:
 - ITER-1D computational benchmark
 - ITER-3D computational benchmark
 - FNSF-3D computational benchmark
 - Sajo1993 Cf-252 iron sphere experimental benchmark
- 4) Future Work



Current D-T Fusion Experiments/Reactors



JET (UK)

- 1983-present
- $R_{\text{major}}=3 \text{ m}$
- $\text{Vol}_{\text{plasma}}=100 \text{ m}^3$
- pulse $\sim 1 \text{ sec}$
- $16 \text{ MW}_{\text{fusion}}$

ITER (France)

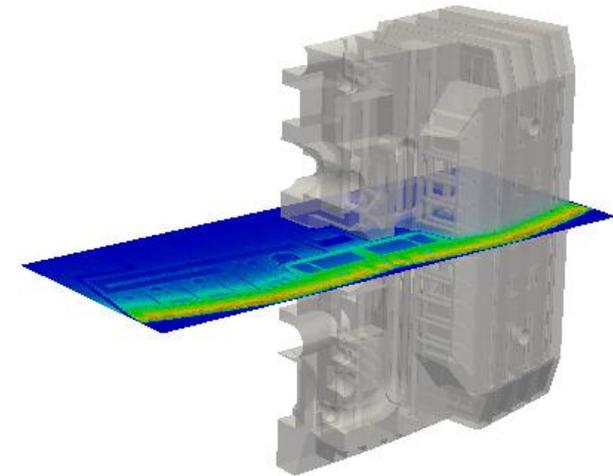
- under construction
- $R_{\text{major}}=6 \text{ m}$
- $\text{Vol}_{\text{plasma}}=840 \text{ m}^3$
- pulse $\sim 400\text{-}600 \text{ sec}$
- $500 \text{ MW}_{\text{fusion}}$

Important Fusion Neutronics Responses



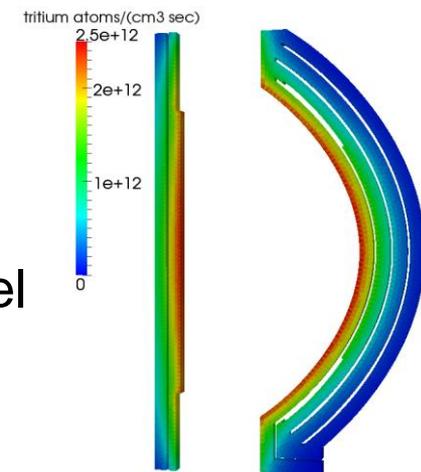
➤ Neutron flux/fluence

- structure, magnets
- Total nuclear heating (**neutron+photon**)
 - coolant system design, thermal stress, etc. for structure, magnets
- Tritium production (**neutron**)
 - breeding fuel, environmental concerns
- Radiation damage/dpa (**neutron**)
 - structural material, magnet degradation
- Helium production (**neutron**)
 - re-weldability
- Radiation dose (**neutron+photon**)
 - insulators, electronics, personnel
- Activation
 - shutdown dose-maintenance robotics, personnel
 - decay heat-safety (LOCA, LOFA)
 - radioactive waste disposal, recycling



Nuclear heating in ITER
FW/Shield Block

Tritium production in FNSF
breeding channel



FENDL Library



- The Fusion Evaluated Nuclear Data Library (FENDL) is an international effort coordinated by the IAEA Nuclear Data Section
- Assembles a collection of the best nuclear data from national cross section data libraries for fusion applications
 - ENDF/B (US), JENDL (Japan), JEFF (Europe), TENDL (EU), RUSFOND/BROND (Russia)
- Process uses **fusion specific** experimental and calculational benchmarks to evaluate the data
- Data available on-line:

International Atomic Energy Agency
Nuclear Data Services
提供核数据服务 原子能机构

Hot Topics • ENDF/B-VII.1 • TENDL-2012 • JENDL-4 • IBANDL News • 50 year anniversary of NDS, June 2014

NEW
JEFF-3.2 - Joint Evaluated Fusion and Fusion File, coord. by NEA Data Bank, 2014 [page] [archive] [retrieve]
IRDFF - International Reactor Dosimetry and Fusion File v1.03 [page] [archive] [retrieve]
CD DVD-ROMs available for on-line downloading [page]
Portable Empire-3.2.2 for Windows - nuclear reaction model code system for data evaluation [page] [download]

Quick Links
ADS-Lib
Atomic Mass Data Centre
CINDA
Charged particle
reference cross section
DROSG 2000
EMPIRE-3.2
ENDF Archive
ENDF Retrieval
ENDF-6 Codes
ENDF-7 Format
ENDF8
ENDF9
ENDF ASCHI Files
ENDF programs
EXFOR
Electron and Photon
Interaction Data
FENDL 3.0
Fusion Neutrons
GANDR

Main | All | Reaction Data | Structure & Decay | by Applications | Doc & Codes | Index | Events | Links | News

EXFOR Experimental nuclear reaction data
LiveChart of Nuclides Interactive Chart of Nuclides
CINDA Nuclear reaction bibliography
ENDF Evaluated nuclear reaction libraries
ENSDF Evaluated nuclear structure and decay data (xJENDL)**
NSR Nuclear Science References*

NuDat 2.6 selected evaluated nuclear structure data**
RIPL reference parameters for nuclear model calculations
IBANDL Ion Beam Analysis Nuclear Data Library
Charged particle reference cross section Blank neutron reactions
PGAA Prompt gamma rays from neutron capture
FENDL 3.0 Fusion Evaluated Nuclear Data Library, Version 3.0
IRDFF International Reactor Dosimetry and Fusion File
NAA Neutron Activation Analysis Portal
Safeguards Data recommendations, August 2008
Medical Portal Data for Medical Applications
Standards Neutron cross-sections, 2006
Decay data, 2005

IAEA Nuclear Data Section
IAEA-NDS Mission, Staff and more
AM Atomic and Molecular Data
Meetings and Workshops
Newsletters
Coordinated Research Projects
NRDC Nuclear Reaction Data Center Network
Nuclear Structure & Decay Data Network
Technical Documents
NDS Reports Publications
Computer Codes

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Nuclear Data Services
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Databases • EXFOR • ENDF • CINDA • IBANDL • Medical • PGAA • NGates • RIPL • FENDL • IRDFF

Documents
CM (2016)
Contents summary
Processing
Validation (Fischer et al., 2014)
Validation (Kopecky, 2012)
Validation (Kopecky, 2012)
Validation (Kopecky, 2015)
Validation (Sulet et al., 2014)
3rd RCM (2011)
2nd RCM (2010)
1st RCM (2009)
TM (2007)
More documents

Links
FENDL-3.1
FENDL-3.0
FENDL-2.1
FENDL-2.0
FENDL-1.0
CRP on FENDL-3.0
Nuclear Data Services
Nuclear Data Section

Contacts
A. Koning
A. Kleyer

**FENDL-3.1d:
Fusion Evaluated Nuclear Data Library Ver.3.1d**
Released on 24 January 2018
(Supersedes the version 3.1c from 19 September 2017)
(Supersedes the version 3.1b from 1 July 2016)
(Supersedes the version 3.1a from 17 September 2015)
(Since 15 Oct. 2015 only Sn-116 and Sn-117 ACE files were added)

Nuclear Data Libraries for Advanced Systems: Fusion Devices

Participants of the Technical Meeting in October/November 2007 (INDC(NDS)-0525) defined the objective of the CRP, which was to update and extend the FENDL-2.1 library to make it applicable to both fusion devices such as ITER and DEMO and to material test facilities such as IFMIF. The extension required the addition of several materials, an extension of the energy range to higher energies and the addition of data for charged particle-induced reactions. Special attention was needed to ensure realistic covariance data that would make the library suitable for all fusion technology studies. The reports of the three RCMs are available (INDC(NDS)-0547, INDC(NDS)-0567 and INDC(NDS)-0602) as well as the summary documentation of the FENDL-3.0 library (INDC(NDS)-0628). A summary of the contributions by participants in the CRP is given in INDC(NDS)-0645.

WARNING
FENDL-3.1d: The only change is the substitution of the minor isotopes K-40 and K-41 with TENDL-2015 for consistency. No impact on any transport calculations is expected.

WARNING
FENDL-3.1d: An extensive validation exercise by R. Grove from ORNL revealed a problem with the K-39 data. The origin of it as follows. At the last RCM Meeting on FENDL a brand new resonance evaluation was announced by the evaluator and recommended for inclusion in FENDL and TENDL. The TENDL team prepared a quick-update, and this modified version was used for FENDL-3.1. The afore-mentioned resonance file was later rejected and did not make it into TENDL-2015, but the information was not conveyed to FENDL. The QA procedures at the IAEA were designed to trap processing errors, but the error in the source evaluated data file slipped through. We apologise for the inconvenience.

The K-39 data from TENDL-2015 were processed and the relevant files were uploaded. The corrected library is labelled FENDL-3.1c. Except for K-39, no other changes were made.

FENDL-3.1c: Due to an error in setting up the processing sequence the uncorrected version of the source ENDF files was used in the version FENDL-3.1, released on 1-st July 2015. The source data were corrected and processing of the whole library was repeated, complete with QA procedures, and is labelled FENDL-3.1b for uniqueness of identification. A few additional problems processing FENDL-3.1 evaluated data were noted, but mostly they had been resolved, or else they originate from the source data and require updating the evaluated data files. They are not expected to affect the results of calculations.

The exception are the MATXS files for Li-7, F-19 and Fe-57. The NJOY patch that forced Doppler-broadening over the entire resolved resonance range resulted in the low-threshold reactions being omitted from the total. The ACE files were not affected. The bug has been fixed. The files for these three nuclides are the only difference between FENDL-3.1a and FENDL-3.1b.

New in Version FENDL-3.1b



Source of FENDL Data



- 65/180 isotopes in FENDL-3 come from the ENDF/B-VII.1 library
 - See Table 1 in INDC(NDS)-0628
- Some key isotopes for this work:

Isotope	FENDL-2.1*	FENDL-3.1
H-1	JENDL-3.3	ENDF/B-VII.1
O-16	ENDF/B-VI.8	ENDF/B-VII.1
Cr-52	ENDF/B-VI.8	ENDF/B-VII.1
Fe-56	JEFF-3	JEFF-3.1.1
Ni-58	JEFF-3	ENDF/B-VII.0
Cu-63,65	ENDF/B-VI.8	ENDF/B-VII.0

*FENDL-2.1 is the reference library for ITER neutronics



ENDF/B-VIII.0 Library



- Released 2018, ACE formatted data available on-line:
 - <https://nucleardata.lanl.gov>
- Initial testing indicated deficiencies in XS for iron
 - revealed in iron transmission experiments with Cf-252 source
 - inelastic XS was too high
- Other structural elements' XS are being re-examined
 - Cr, Co, Ni, Ti, Pb
- Candidate replacements for some isotopes of Fe and Cr have been made available for this work* (*provided by A. Trkov*)

• A. Trkov, R. Capote, "INDEN (Post-CIELO) ^{56}Fe Evaluation", Consultants Meeting on the FENDL Library for fusion neutronics calculations, 15-18 Oct., IAEA, 2018.

• G.P.A Nobre, D.A. Brown, "Nuclear Data Evaluations of Structural Materials in BNL", INDEN Consultants Meeting on Evaluation of Structural Materials, Oct. 29-Nov. 1, IAEA, 2018.

• A. Trkov et al. "Improved evaluations of neutron induced reactions on ^{57}Fe and ^{56}Fe targets, Consultants Meeting of INDEN on Evaluated Nuclear Data of the Structural Materials, 2-5 Dec., IAEA, 2019.

• G.P.A. Nobre et al. "Status of Cr Evaluations", Consultants Meeting of INDEN on Evaluated Nuclear Data of the Structural Materials, 2-5 Dec., IAEA, 2019.

• * See the IAEA INDEN web site: <https://www-nds.iaea.org/INDEN/>



Goal of this work



➤ Look at the neutronics impact of using the updated neutron libraries in a **realistic model of fusion systems** using MCNP

➤ Libraries examined:

- Neutron:

1. FENDL-2.1 (21c)
2. FENDL-3.1 (31c)-current version 3.1d
3. ENDF/B-VII.1 (80c)
4. ENDF/B-VIII.0 (00c)

standard MCNP id

5. New candidate evaluations for Fe, Cr

New work

- Photon*:

1. mcplib84 (84p)

➤ **Previous work has shown that mcplib84 produces results similar to the newer MCNP eprdata12 library, the latest MCNP photon library (eprdata14) has not been tested yet*

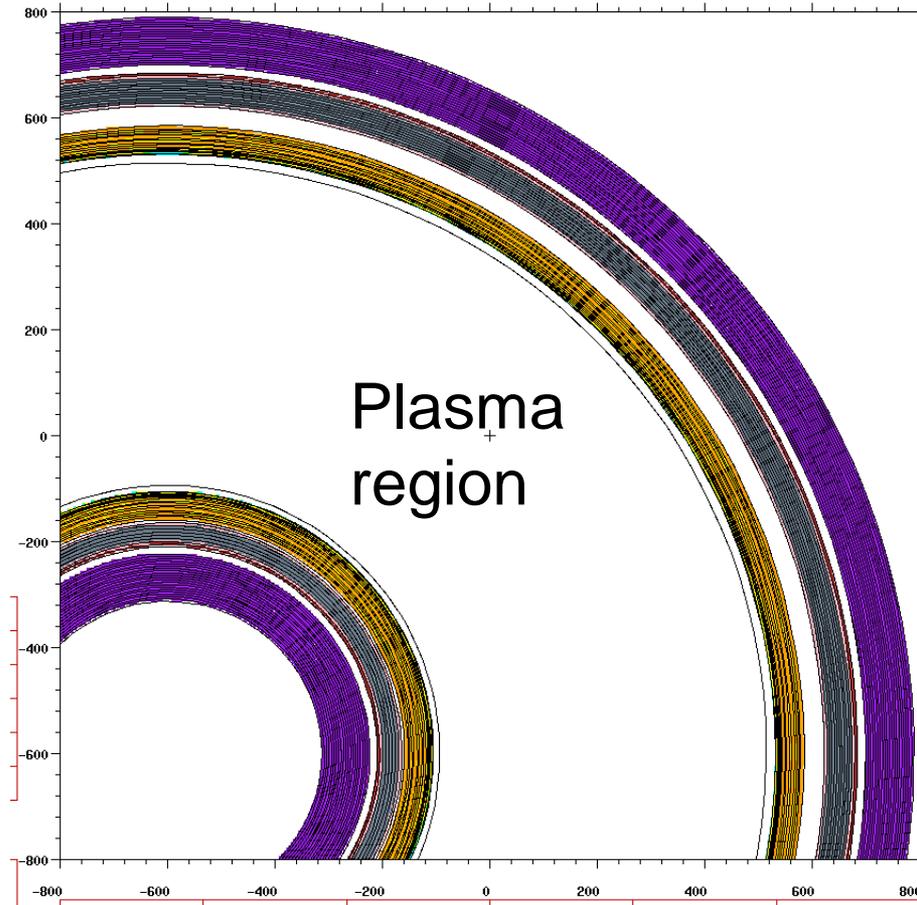
**Bohm T.D, Sawan M.E. "The impact of updated cross section libraries on ITER neutronics calculations", Fusion Science and Technology, Vol 68 p. 331-335, 2015.*



ITER 1-D Cylindrical Calculation Benchmark



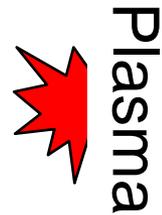
- Based on an **early** ITER design
- Developed for the FENDL evaluation process
- Simple but realistic model of ITER with the Inboard and Outboard portions modeled with the plasma in between
- D-T fusion (14.1 MeV neutrons)
- Flux (neutron and photon), heating, dpa, and gas production calculated



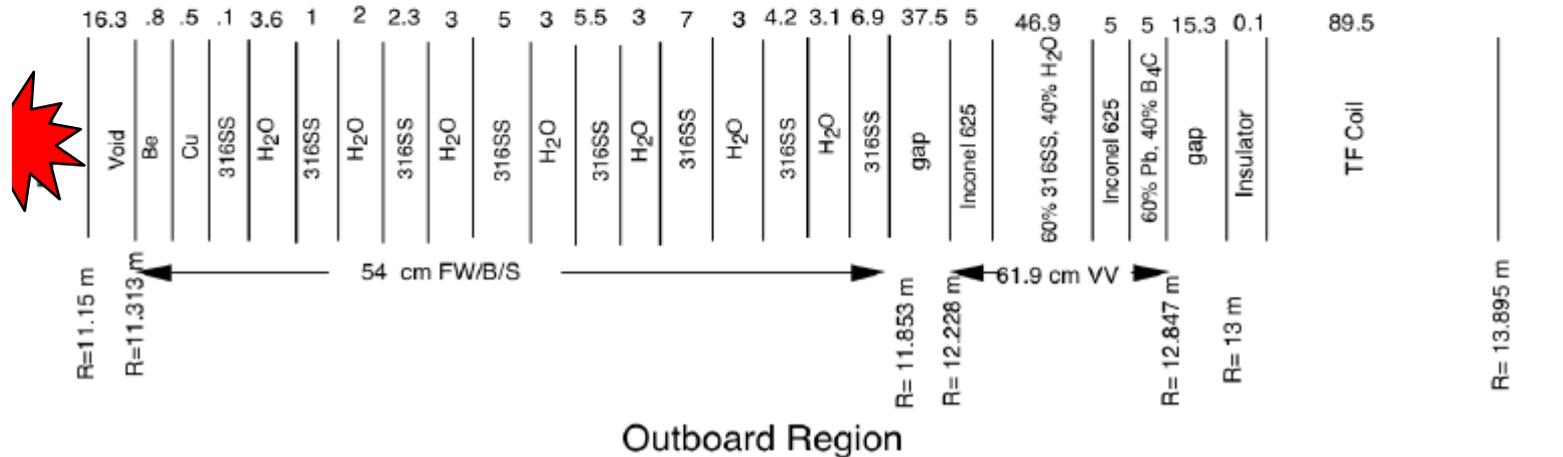
M. Sawan, FENDL Neutronics Benchmark: Specifications for the calculational and shielding benchmark, INDC(NDS)-316, December 1994



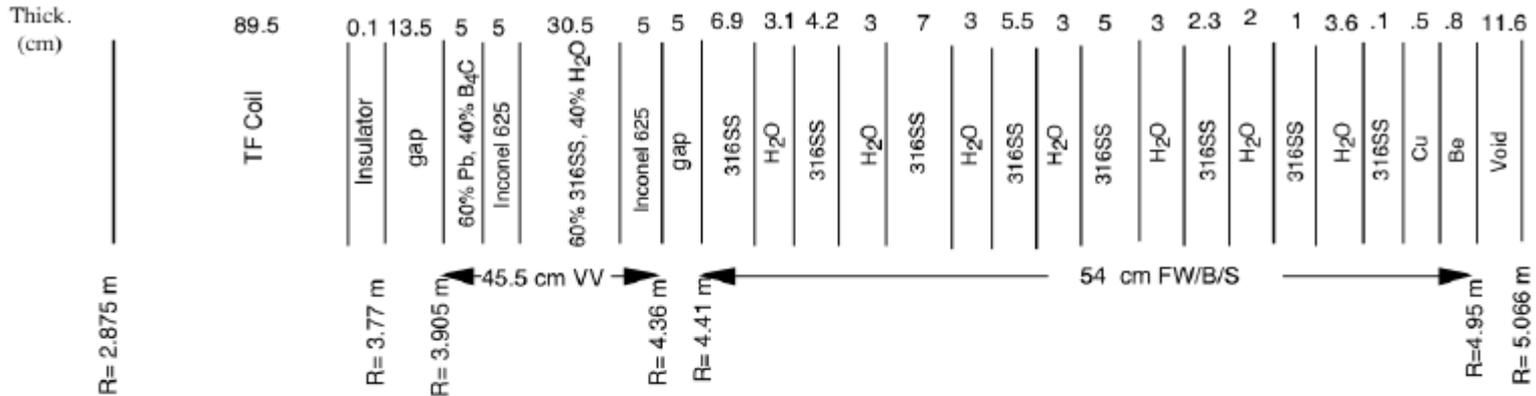
ITER 1-D Cylindrical Benchmark continued



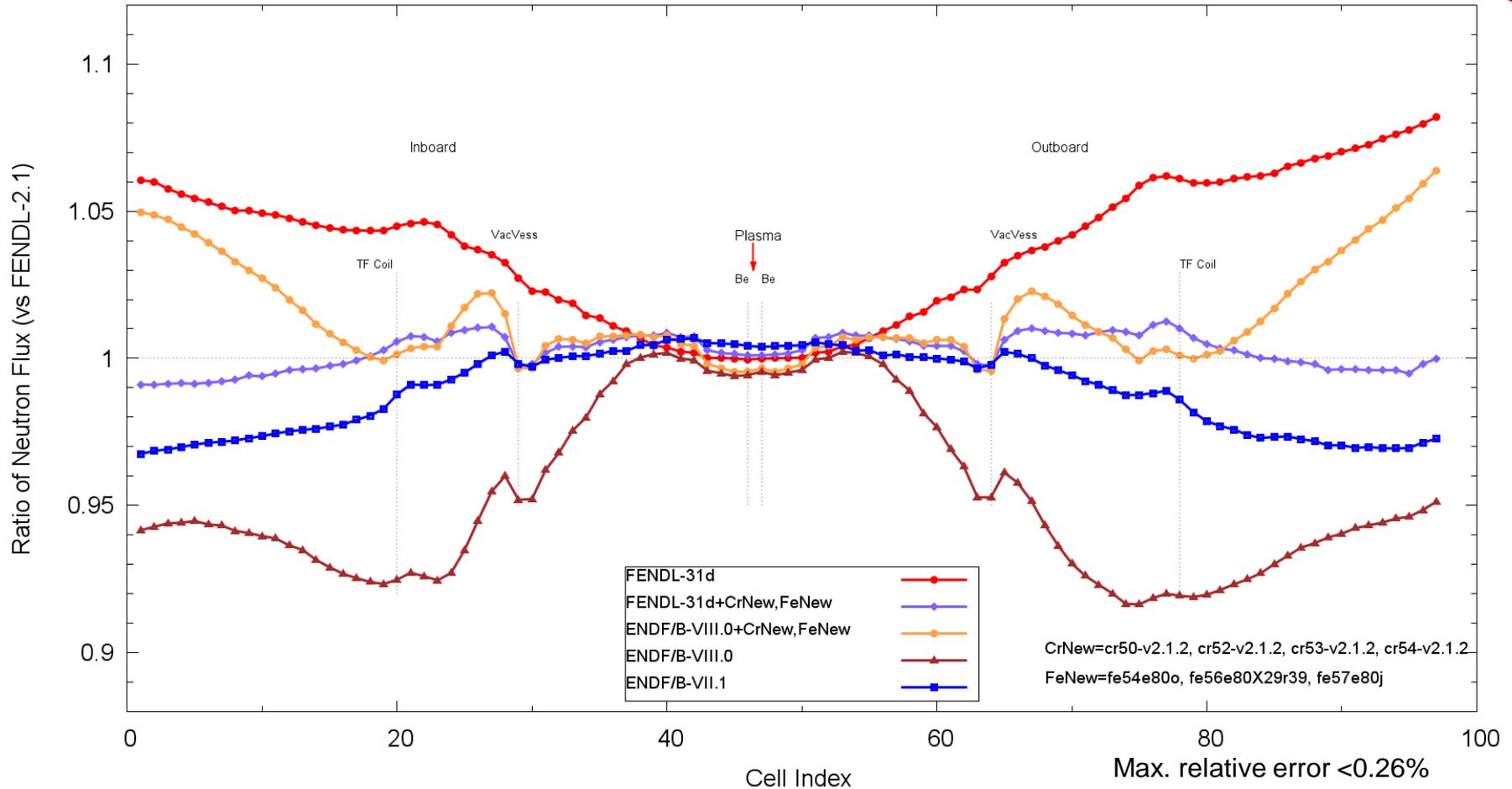
Plasma



Inboard Region



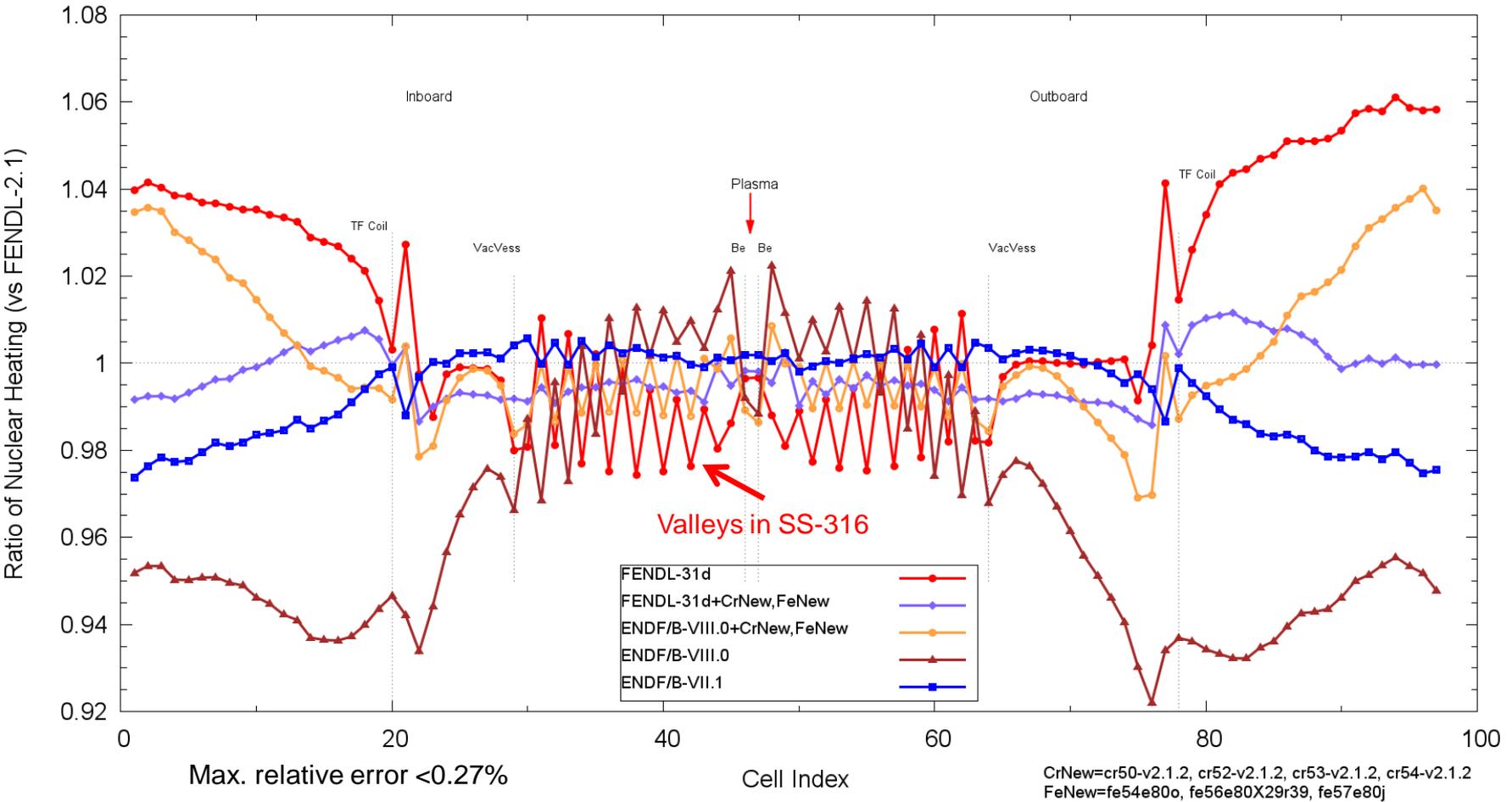
Results: Neutron Flux



- With FENDL-3.1, we see neutron fluxes up to 8% higher than FENDL-2.1
- With ENDF/B-VIII.0 we see neutron fluxes up to 8% lower than FENDL-2.1
- ENDF/B-VIII.0+CrNew,FeNew closer to FENDL-2.1 but see structure at VV, TFC
- FENDL-3.1+CrNew,FeNew quite close to FENDL-2.1 but structure at VV



Results: Total Nuclear Heating



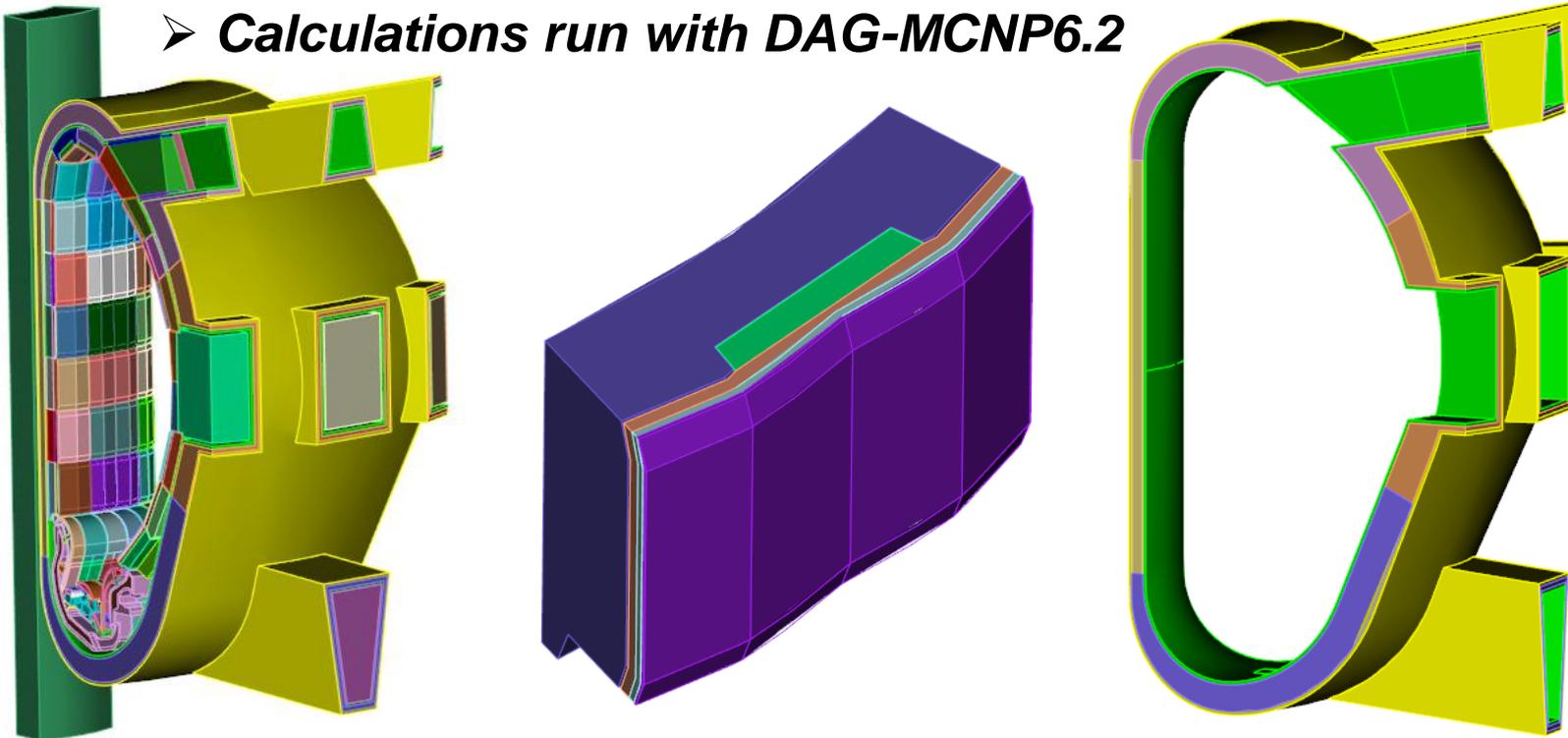
- With FENDL-3.1, we see heating up to 6% higher than FENDL-2.1
- With ENDF/B-VIII.0 we see heating up to 8% lower than FENDL-2.1
- ENDF/B-VIII.0+CrNew,FeNew closer to FENDL-2.1 but see structure at VV, TFC
- FENDL-3.1+CrNew,FeNew quite close to FENDL-2.1 but structure at TFC

3-D ITER CAD Model



- Based on UW BL-Lite model with added IB Toroidal Field Coil (TFC) volume
- All BMs homogenized and consist of 5 volumes (Be layer, Cu layer, SS finger layer, Beam layer, SB)
- VV consists of 3 homogenized parts (inner shell, body, outer shell)
- Model has 723 volumes, 12067 surfaces, 29467 curves

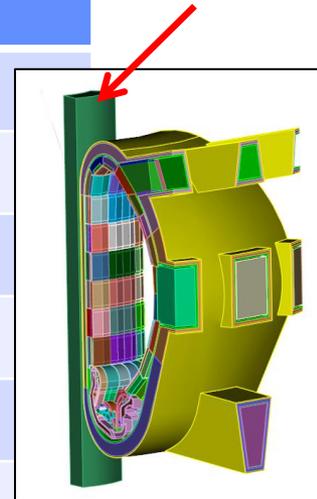
➤ **Calculations run with DAG-MCNP6.2**



Results- total nuclear heating IB TFC



Library	Tally IB TFC (W/cm ³)	Ratio
FENDL-2.1	3.72244E-05	1
FENDL-3.1	3.73618E-05	1.004
ENDF/B-VII.1	3.62283E-05	0.973
ENDF/B-VIII.0	3.44391E-05	0.925
ENDF/B-VIII.0 + CrNew,FeNew	3.61820E-05	0.972
FENDL-3.1 + CrNew,FeNew	3.70739E-05	0.996



Max. relative error <0.66%

- With FENDL-3.1, we see heating the same as FENDL-2.1 at IB TFC
- With ENDF/B-VIII.0 we see heating 7% lower than FENDL-2.1
- With ENDF/B-VIII.0+CrNew,FeNew we see heating 3% lower than FENDL-2.1
- With FENDL-3.1+CrNew,FeNew we see heating the same as FENDL-2.1
- *This is consistent with what we saw in 1-D model at the front of the TFC*

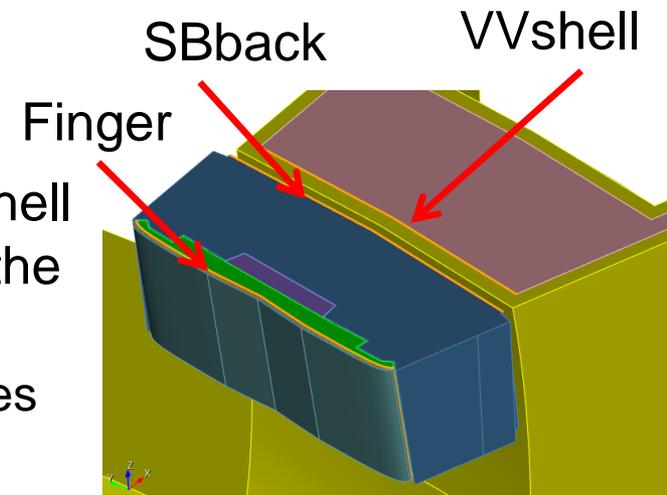


Results: Iron dpa near BM14 (ratios)



Location	F-2.1	E-VII.1	F-3.1	E-VIII.0	E-VIII.0 + CrNew,FeNew	F-3.1 + CrNew,FeNew
Finger	1.000	1.062	0.997	1.000	0.997	0.997
SBback	1.000	1.015	1.009	0.964	1.000	0.995
VVshell	1.000	1.019	1.010	0.968	1.004	0.998

Maximum relative error <0.10%



- For ITER, the main concern for dpa is at the VV shell
- With ENDF/B-VIII.0 we see 3-4% lower dpa than the other libraries
 - In general, close agreement among the other libraries at all locations
- With ENDF/B-VII.1 we see an outlier at the BM Finger



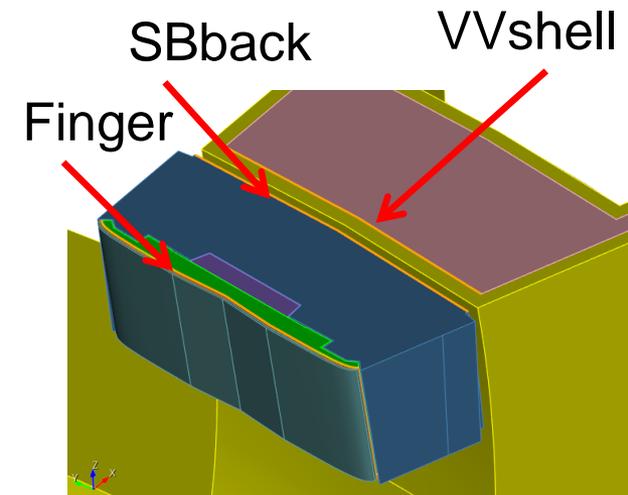
Results: He production near BM14 (ratios)



Location	F-2.1	E-VII.1	F-3.1	E-VIII.0	E-VIII.0 + CrNew,FeNew	F-3.1 + CrNew,FeNew
Finger	1.000	1.081	1.042	1.078	1.136	1.157
SBback	1.000	1.048	1.056	1.037	1.095	1.108
VVshell	1.000	1.079	1.057	1.066	1.127	1.144

Maximum relative error <0.13%

- For ITER, the main concern for He production is at the back of the SB and the VV shell for re-welding
- Overall, He production is 4-8% higher with previous libraries
- Libraries using the new Cr and Fe evaluations are 10-16% higher than that calculated with FENDL-2.1
 - We will need to check the He production XS and spectra to determine the underlying cause

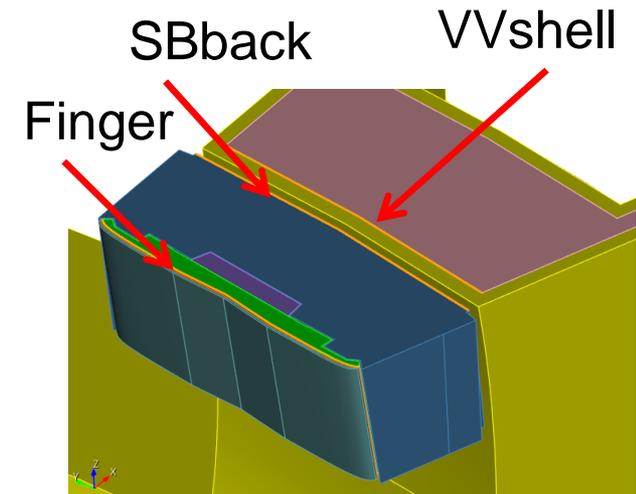


Results: He production near BM14 (ratios)



- Calculate He production using FENDL-2.1 for transport, and various libraries for He production response function (mt 207) in SS-316 L(N)-IG (17.5 w/o Cr)

Mt 207 Library	Finger	SBback	Vvshellback
FENDL-2.1	1.000	1.000	1.000
ENDF/B-VII.1	1.071	1.048	1.073
FENDL-3.1d	1.041	1.032	1.037
ENDF/B-VIII.0	1.080	1.057	1.086
E-VIII.0 + CrNew,FeNew	1.134	1.082	1.129
F-3.1 + CrNew,FeNew	1.149	1.098	1.141



Maximum relative error <0.13%

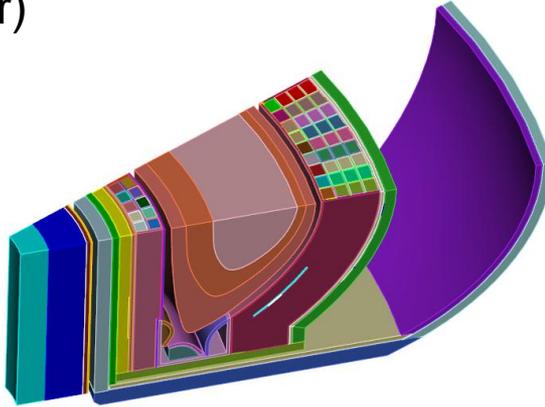
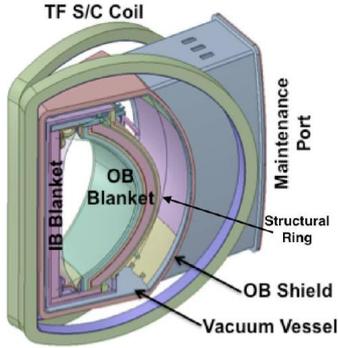
- With the CrNew,FeNew evaluations, we see most of the differences in He production at these locations are due to the change in He production XS



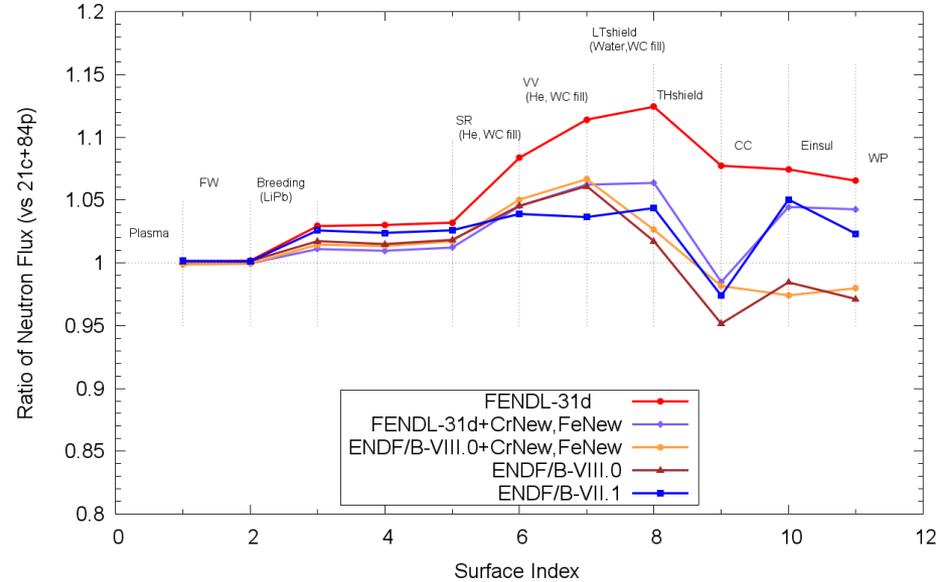
Other Work-FNSF Computational Benchmarking



➤ Need to test on fusion designs other than ITER (different structural materials and tritium breeder)



Neutron flux:



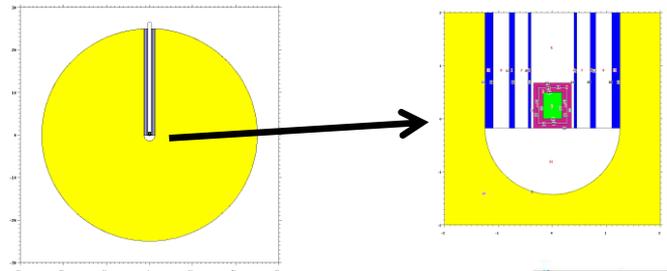
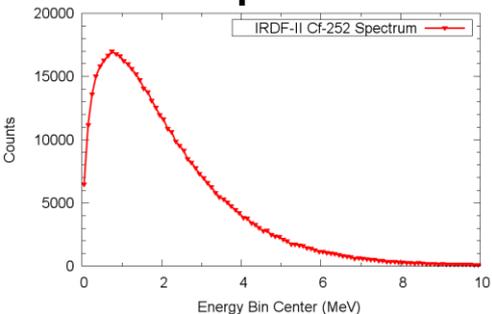
Nuclear heating at VV and Magnet coil case:

Library	IB VV (MW)	Ratio	IB Coil Case (MW)	Ratio
FENDL-2.1	1.7573E-01	1	7.1836E-05	1
ENDF/B-VIII.0	1.8418E-01	1.048	7.7464E-05	1.08
FENDL-3.1	1.8521E-01	1.054	8.1532E-05	1.14
ENDF/B-VII.1	1.8038E-01	1.026	7.7310E-05	1.08
E-VIII.0+CrNew,FeNew	1.8439E-01	1.049	7.7924E-05	1.09
F-3.1+CrNew,FeNew	1.8384E-01	1.046	7.8837E-05	1.10



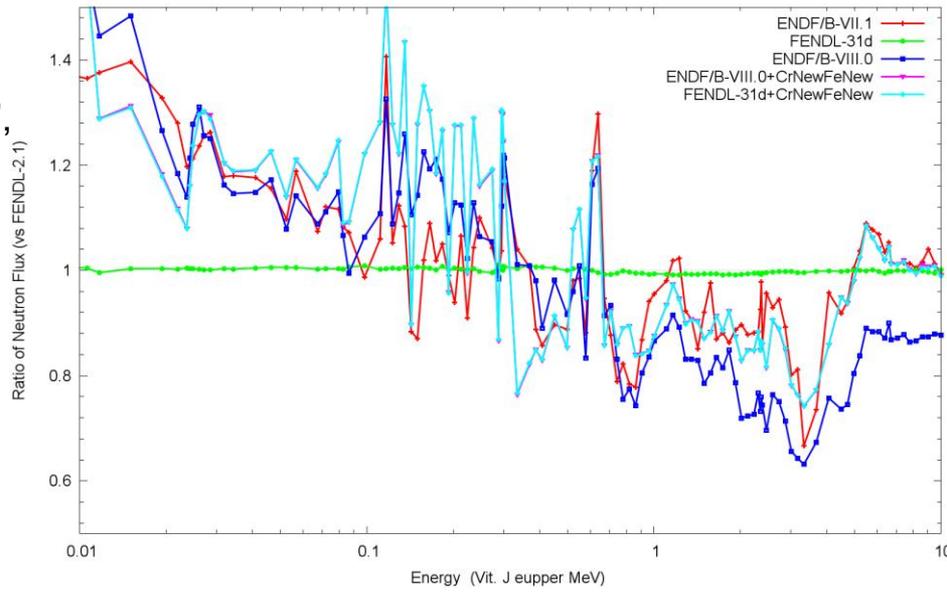
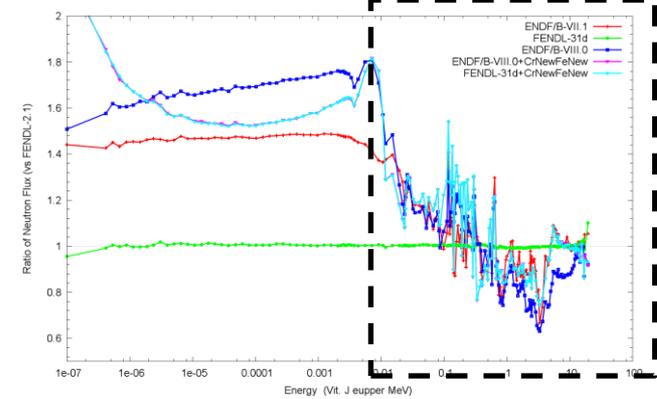
Other Work: MCNP model of Sajo Iron Sphere Experiment

➤ Encapsulated Cf-252 source in 25 cm iron sphere



Yellow=iron (99.42 w/o Fe)
 Blue=AlCu alloy (93.9 w/o Al)
 Pink=SS304
 Green=Cf

E. Sajo, et al, "Comparison of Measured and Calculated Neutron Transmission Through Steel for a 252-Cf Source", Ann. Nucl. Energy, Vol. 20, No. 9, page 585-604, 1993



- With FENDL-3.1d, we see a close match to fluxes calculated with FENDL-2.1
- With ENDF/B-VIII.0, we see lowest fluxes in the E=1 to 10 MeV region vs. FENDL-2.1
- With new evaluations added, see results similar to FENDL-3.1 in E=1-10 MeV

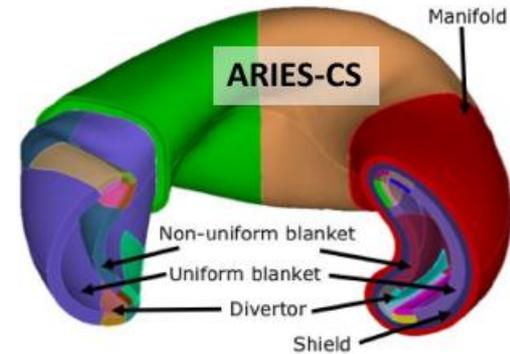
Backup slides



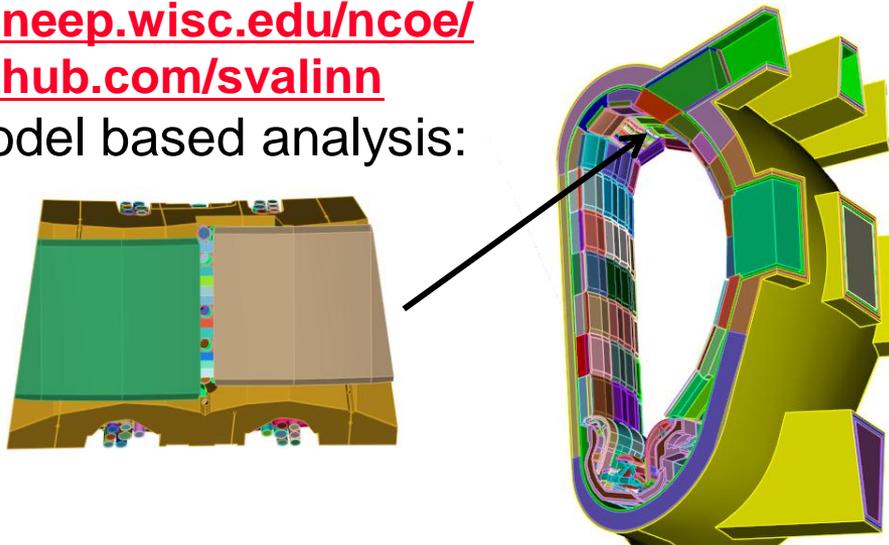
UW Neutronics Capabilities (3-D)



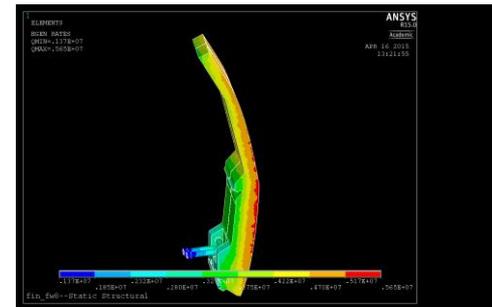
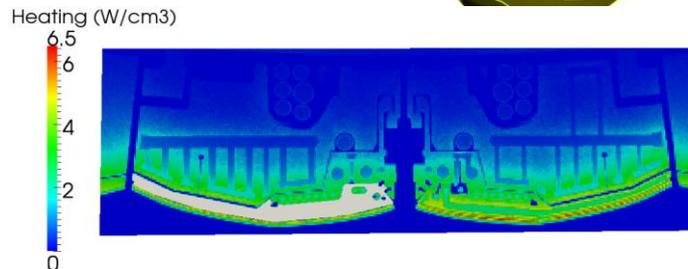
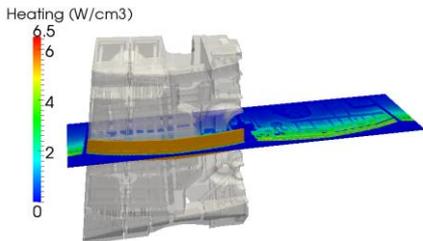
- DAGMC (detailed 3-D CAD based Monte Carlo transport)
 - Transports directly in the CAD model (not a translator)
 - Handles complex surfaces without simplification
 - Couples to MCNP, Geant4, FLUKA, SHIFT, OpenMC
 - Provides a common domain for coupling to other analysis
 - <http://fti.neep.wisc.edu/ncoe/>
 - <http://github.com/svalinn>
- 3-D CAD model based analysis:



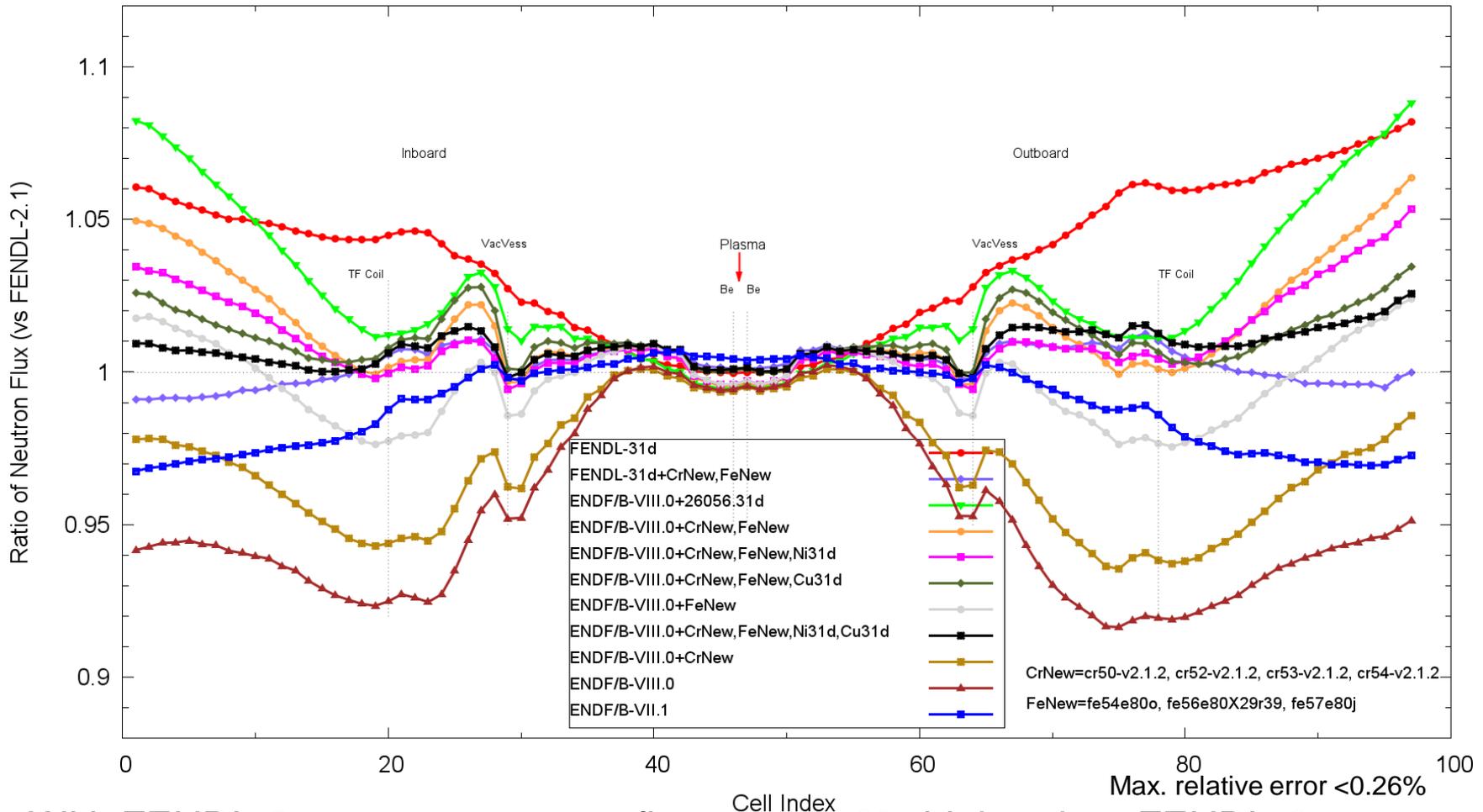
ITER BM08



Nuclear heating mapped to ANSYS mesh for thermal analysis



ITER-1D Neutron Flux (isotopic substitution study)



- With FENDL-3.1, we see neutron fluxes up to 8% higher than FENDL-2.1
- With ENDF/B-VIII.0 we see neutron fluxes up to 8% lower than FENDL-2.1
- ENDF/B-VIII.0+CrNew, FeNew closer to FENDL-2.1 but see structure at VV, TFC
- FENDL-3.1+CrNew, FeNew quite close to FENDL-2.1 but structure at VV



ITER-1D Results: dpa (% difference vs. FENDL-2.1)



	FENDL-2.1	FENDL-3.1d	ENDF/B-VII.1	ENDF/B-VIII.0	FENDL-3.1d +CrNew,FeNew	ENDF/B-VIII.0 +CrNew,FeNew
IB						
FW Cu (Cu)	0	-0.32	0.22	-1.16	-0.26	-1.03
FW SS (Fe)	0	-0.07	5.58	0.15	-0.47	-0.37
VV Inc. (Ni)	0	3.03	0.09	-7.96	0.22	-2.24
VV SS (Fe)	0	2.74	3.25	-3.69	1.52	1.66
Mag. (Cu)	0	4.52	-1.01	-8.96	1.04	-1.47
OB						
FW Cu (Cu)	0	-0.28	0.14	-1.04	-0.23	-0.94
FW SS (Fe)	0	-0.03	5.66	0.10	-0.49	-0.40
VV Inc. (Ni)	0	3.07	0.04	-7.95	0.19	-2.33
VV SS (Fe)	0	2.82	3.28	-3.44	1.57	1.76
Mag. (Cu)	0	6.30	-1.17	-9.27	1.60	-1.14

Max. relative error <0.15%

- different neutron flux and spectrum at FWSS, VV, magnet
- dpa values higher for FENDL-3.1d than FENDL-2.1 (up to 6%)
- dpa values lower for ENDF/B-VIII.0 than FENDL-2.1 (up to 9%)
- With the new evaluations for Cr and Fe, dpa values within 2.4%



ITER-1D Results: He production (% diff. vs. FENDL-2.1)



	FENDL-2.1	FENDL-3.1d	ENDF/B-VII.1	ENDF/B-VIII.0	FENDL-3.1d +CrNew,FeNew	ENDF/B-VIII.0 +CrNew,FeNew
IB						
FW Be	0	0.04	0.60	0.80	0.08	0.92
FW CuBeNi	0	0.39	0.91	3.70	0.49	3.84
FW SS316	0	4.24	6.37	6.16	13.00	10.30
VV Inconel	0	17.96	13.58	6.84	19.41	15.28
VV SS316	0	8.06	4.52	1.26	11.28	8.75
Mag. (Cu)	0	5.02	-0.20	-1.17	1.91	4.95
OB						
FW Be	0	0.07	0.50	0.90	0.12	0.99
FW CuBeNi	0	0.47	0.87	3.75	0.54	3.85
FW SS316	0	4.41	7.09	6.98	14.16	11.62
VV Inconel	0	17.98	13.51	6.96	19.33	15.33
VV SS316	0	8.07	4.61	1.49	11.29	8.71
Mag. (Cu)	0	6.86	-0.62	-1.52	2.55	5.72

Max. relative error <0.19%

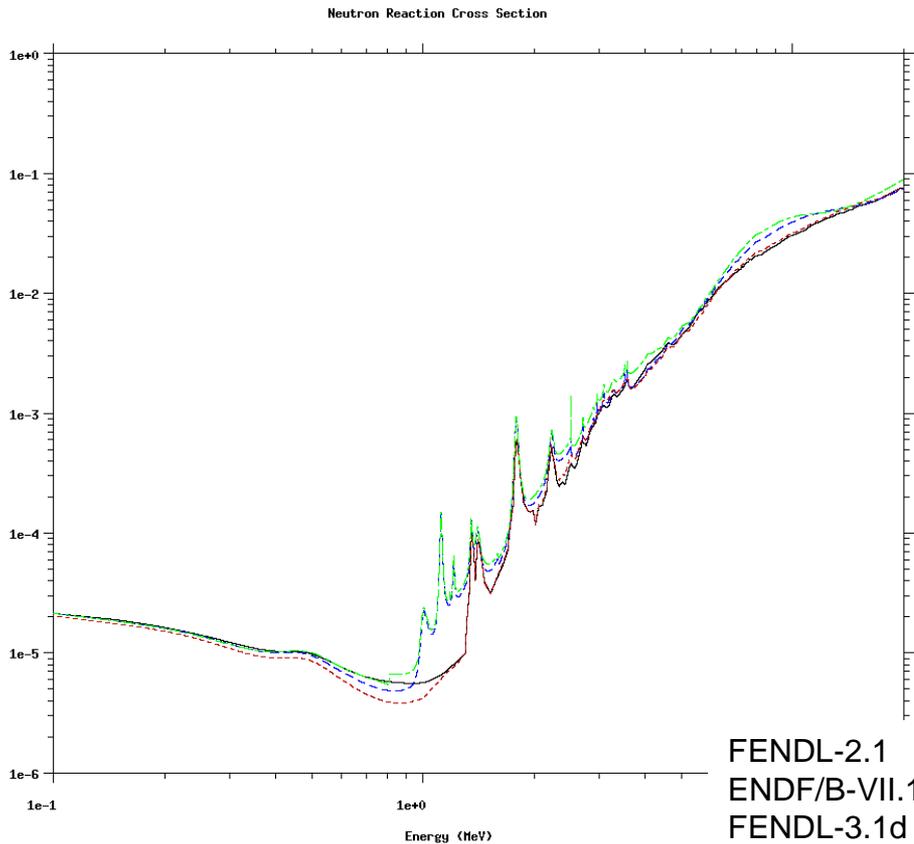
- He production values higher for FENDL-3.1d than FENDL-2.1 (up to 18%)
- He production values higher for ENDF/B-VIII.0 than FENDL-2.1 (up to 7%) except magnet (lower)
- Libraries with the new Cr and Fe evaluations:
 - He production up to 19% higher in VV Inconel than FENDL-2.1
 - He production 9-14% higher in SS316



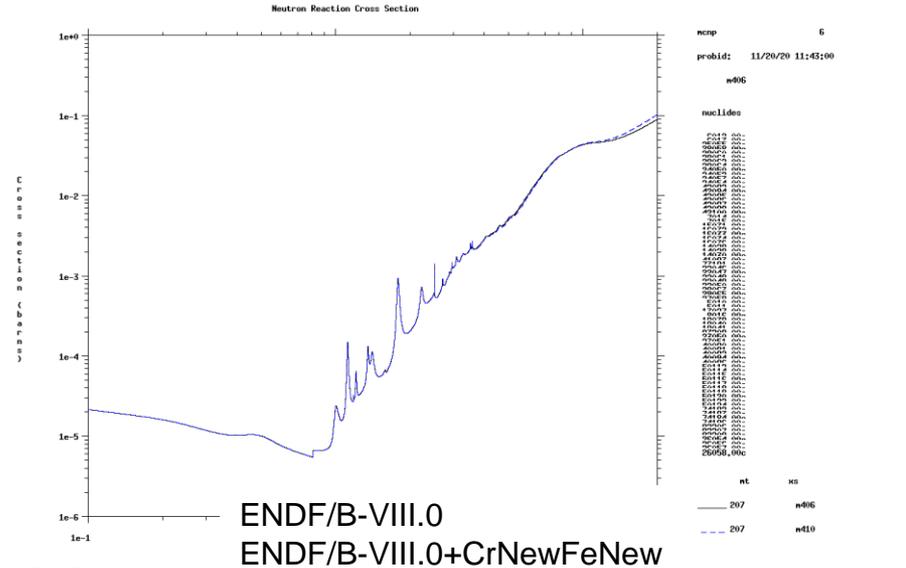
He production XS (mt 207) SS-316 L(N)-IG (17.5 w/o Cr)



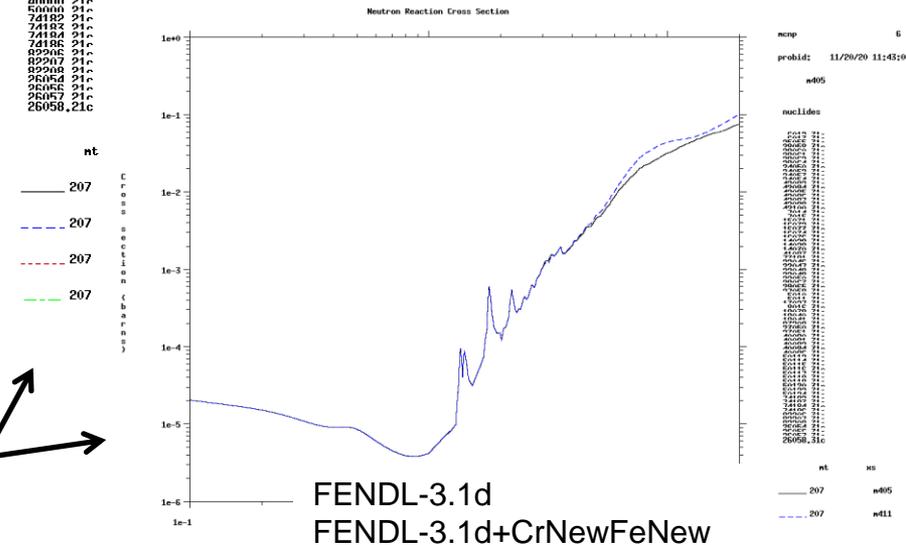
Cross section (barns)



FENDL-2.1
 ENDF/B-VII.1
 FENDL-3.1d
 ENDF/B-VIII.0



ENDF/B-VIII.0
 ENDF/B-VIII.0+CrNewFeNew

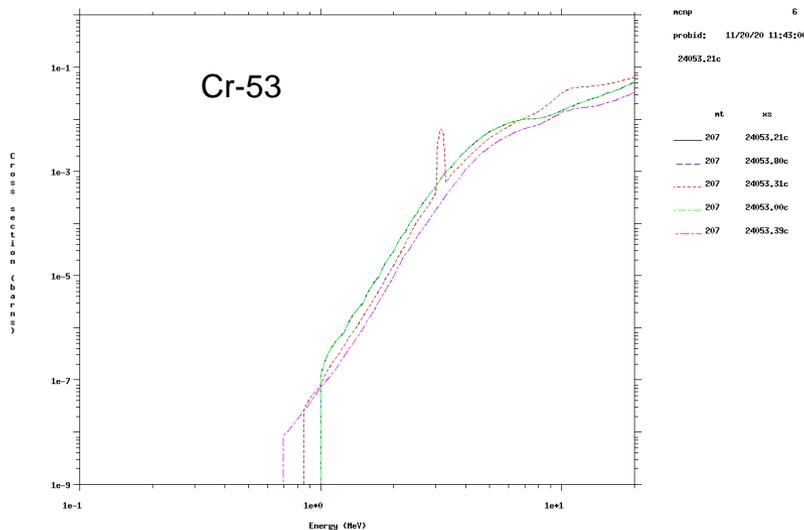
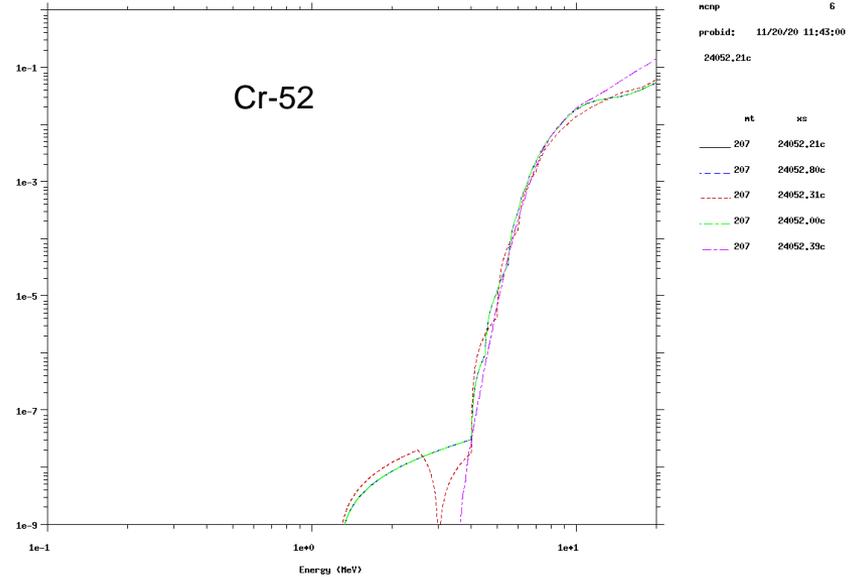
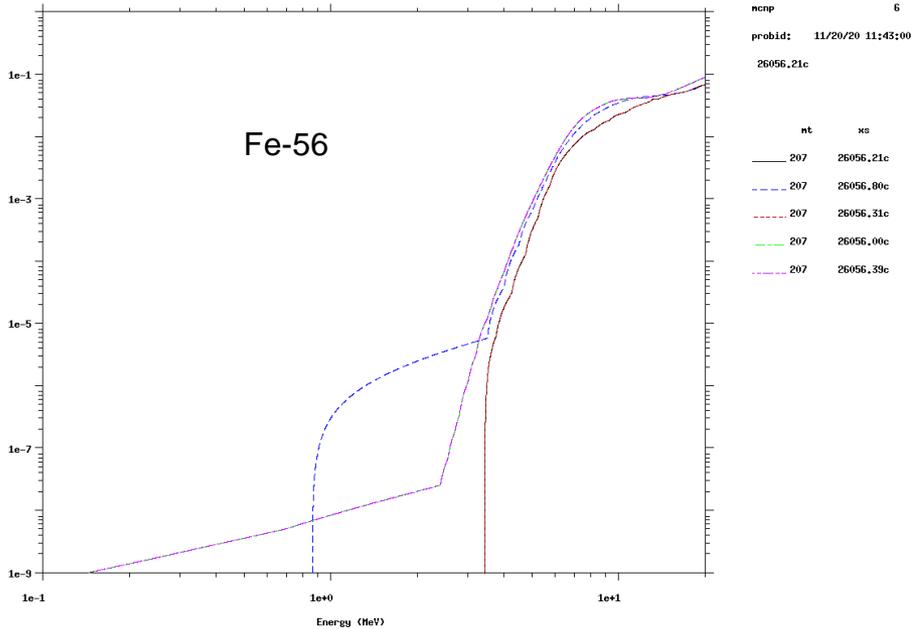


FENDL-3.1d
 FENDL-3.1d+CrNewFeNew

➤ He production XS for new evaluations higher near 10 MeV



He production XS (mt 207) Cr and Fe



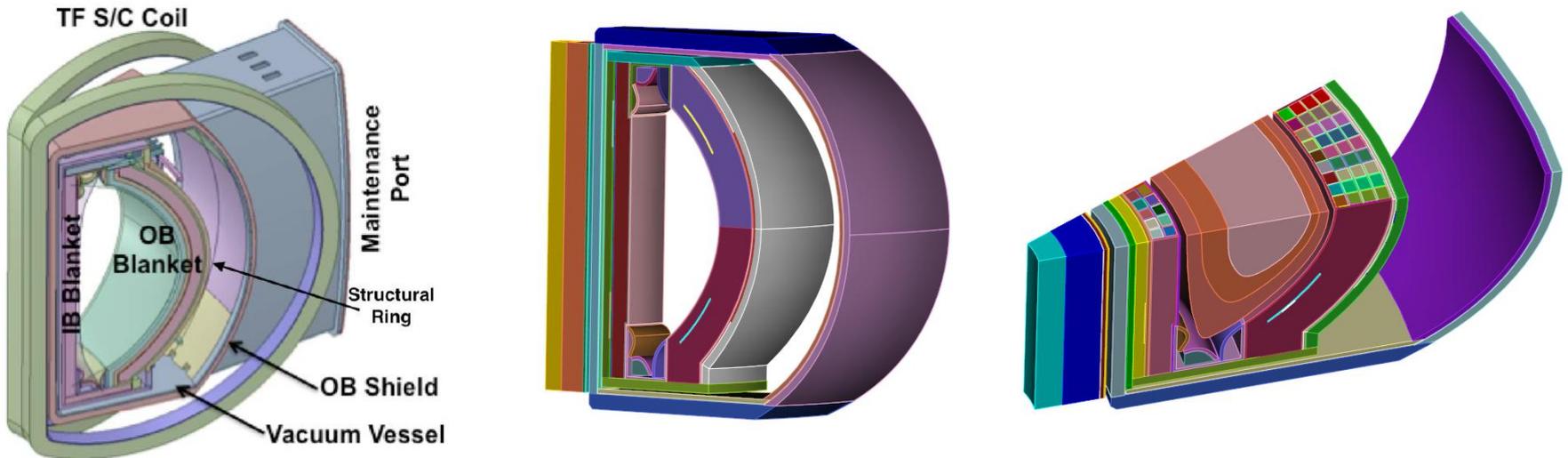
21c=FENDL-2.1
 31c=FENDL-3.1d
 80c=ENDF/B-VII.1
 00c=ENDF/B-VIII.0
 39c=New Evaluation

➤ He production XS for FENDL-2.1 and ENDF/B-VII.1 are overlapping



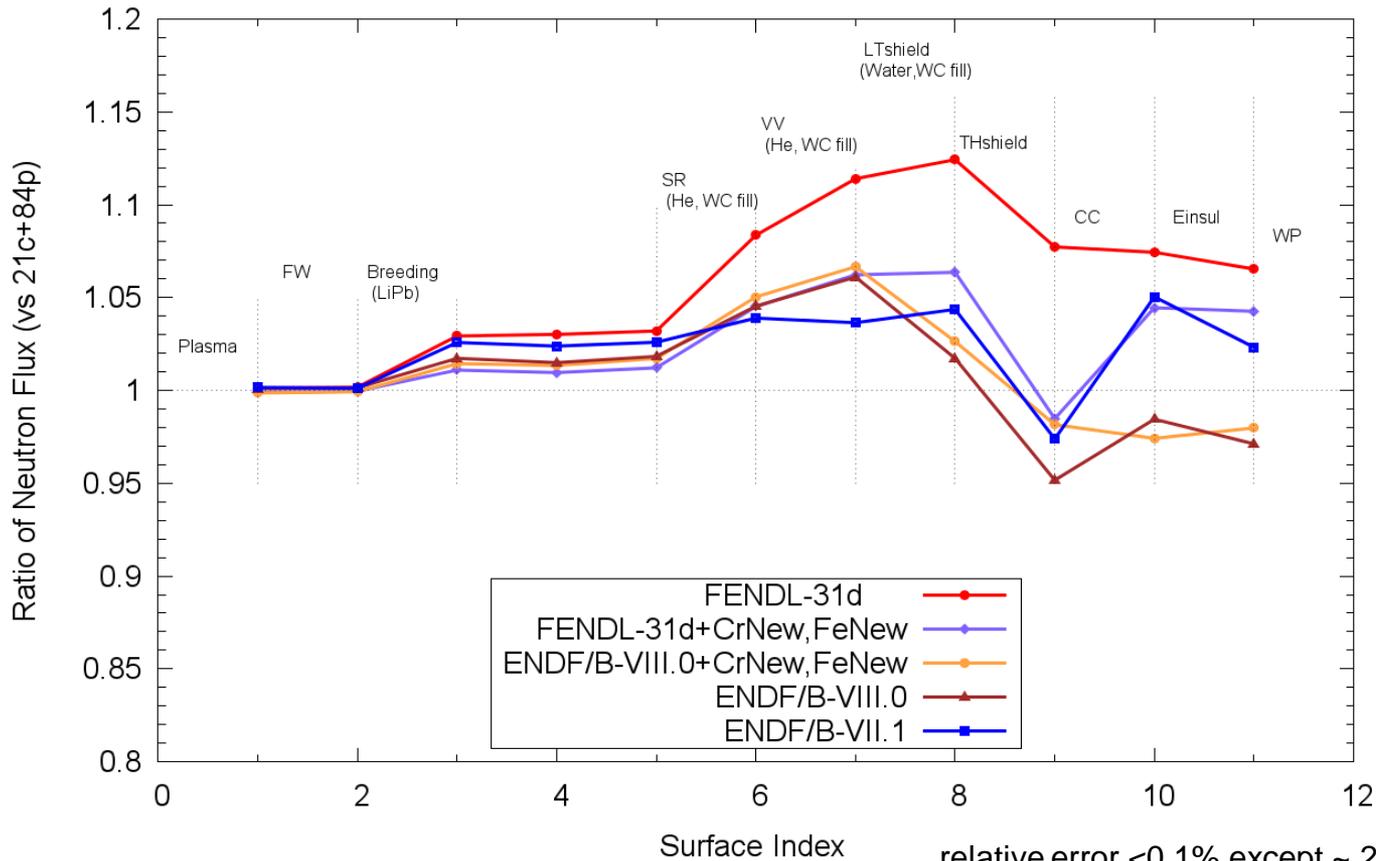
3-D FNSF Model

- U.S. Fusion Nuclear Science Facility (step to DEMO)
 - Single sector (22.5 deg.) neutronics model:
 - No ports, 2 cm straight gaps between sectors
 - 518 MW fusion power, 3 region plasma source model
 - PbLi breeding region detailed, other components partially homogenized
- **Calculations run with DAG-MCNP6.2**



A. Davis et al. "Neutronics aspects of the FESS-FNSF", *Fusion Engineering and Design*, 2017.
 T. Bohm et al. "Initial Neutronics Investigation of a Liquid Metal Plasma Facing Fusion Nuclear Science Facility", *Fusion Science and Technology*, 2019.

FNSF Results- IB neutron flux



relative error <0.1% except ~ 2% at TH shield-WP

- With FENDL-3.1 neutron library see neutron fluxes up to 12% higher than FENDL-2.1
- With ENDF/B-VIII.0 we see neutron fluxes 5% lower at coil case
- Adding the new Cr and Fe evaluations brings neutron fluxes closer to FENDL-2.1
- These trends are similar to what was seen in the ITER-1D model



FNSF Results-total nuclear heating



Library	IB VV (MW)	Ratio	IB Coil Case (MW)	Ratio
FENDL-2.1	1.7573E-01	1	7.1836E-05	1
ENDF/B-VIII.0	1.8418E-01	1.048	7.7464E-05	1.08
FENDL-3.1	1.8521E-01	1.054	8.1532E-05	1.14
ENDF/B-VII.1	1.8038E-01	1.026	7.7310E-05	1.08
E-VIII.0+CrNew,FeNew	1.8439E-01	1.049	7.7924E-05	1.09
F-3.1+CrNew,FeNew	1.8384E-01	1.046	7.8837E-05	1.10

VV is 3CrFS, WC filler, He cooled
Magnet Coil Case is SS316

VV relative error <0.03%
Coil Case relative error <1.3%

- At the VV, heating values are ~5% higher than FENDL-2.1 for all libraries except ENDF/B-VII.1 (~3%)
- At the CC, heating values are 8-14% higher as compared to FENDL-2.1
- This is different than seen with the ITER-1D model (tended to be lower than FENDL-2.1)

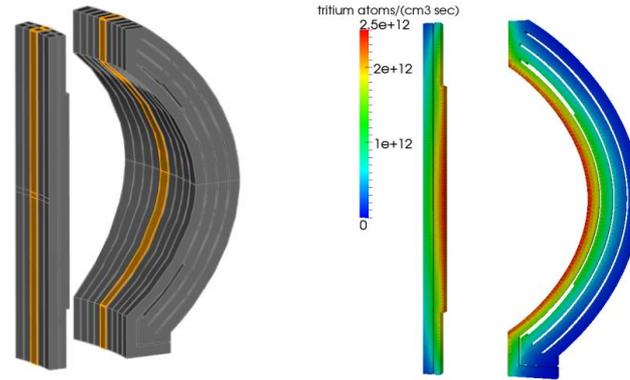


Results-Tritium Breeding Ratio



➤ FNSF uses PbLi for breeding:

- 84.3 atomic% Pb
- 15.7 atomic% Li (enriched to 90% Li-6)



Library	IB TBR	Ratio	OB TBR	Ratio
FENDL-2.1	0.2961	1	0.8135	1
ENDF/B-VIII.0	0.3003	1.014	0.8265	1.016
FENDL-3.1	0.3000	1.013	0.8274	1.017
ENDF/B-VII.1	0.2997	1.012	0.8241	1.013
E-VIII.0+CrNew,FeNew	0.2987	1.009	0.8235	1.012
F-3.1+CrNew,FeNew	0.2986	1.008	0.8239	1.013

Max. relative error <0.01%

- We see TBR ~1-1.7% higher than that calculated with FENDL-2.1



FNSF Results-Fe dpa (ratio)



Library	IB FW	IB VV
FENDL-2.1	1	1
ENDF/B-VIII.0	1.010	1.060
FENDL-3.1	1.001	1.092
ENDF/B-VII.1	1.060	1.092
E-VIII.0+CrNew,FeNew	1.008	1.083
F-3.1+CrNew,FeNew	1.003	1.083

FW is MF82H (7.5 w/o Cr), VV is 3CrFS (3 w/o Cr)

VV relative error <0.27%

- At the FW, dpa values are very close except for ENDF/B-VII.1
- At the VV, dpa values are 6-9% higher for all libraries compared to FENDL-2.1
- With the new evaluations for Cr and Fe:
 - Fe dpa values are close at the FW
 - Fe dpa values are 8% higher at the VV



FNSF Results-He production (ratio)



Library	IB FW	IB VV
FENDL-2.1	1	1
ENDF/B-VIII.0	1.093	1.120
FENDL-3.1	1.006	1.002
ENDF/B-VII.1	1.075	1.093
E-VIII.0+CrNew,FeNew	1.127	1.137
F-3.1+CrNew,FeNew	1.135	1.151

FW is MF82H (7.5 w/o Cr), VV is 3CrFS (3 w/o Cr) VV relative error <0.27%

- At the FW, He production values are similar for FENDL-3.1d but the others are 8-14% higher
- At the VV, He production values are similar for FENDL-3.1d but the others are 9-15% higher
- With the new evaluations for Cr and Fe, He production is 13-15% higher

